PRODUCT DATA

Sound Intensity Probe Kit for Type 2270 — Type 3654
Sound Intensity Microphone Pair — Type 4197
Dual Preamplifier — Type 2683

Type 3654 is a two-microphone probe kit for measuring sound intensity. Designed for use with Hand-held Sound Intensity System Type 2270, the probe set includes the 1/2″ Sound Intensity Microphone Pair Type 4197 enabling 1/3-octave centre frequency measurements between 20 Hz and 6.3 kHz. Extending the upper 1/3-octave centre frequency to 10 kHz can be achieved using pressure correction.

Used with 1/2″ Microphone pair Type 4197, the probe complies with IEC 1043 Class 1. These 1/2″ microphones feature patented phase-corrector units making precision low-frequency phase matching practical, leading to increased measurement range and accuracy.

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Uses and Features

Uses
- Sound intensity measurements using two-microphone technique in accordance with IEC 1043 Class 1
- Sound power measurements in accordance with ISO 9614 – 1, ISO 9614 – 2, ECMA 160 and ANSI S 12 – 12

Features
- Microphone pair matched for phase and amplitude response
- Individual calibration data
- 1/3-octave centre frequency ranges:
  – 20 Hz to 10 kHz with corrections
  – 50 Hz to 6.3 kHz according to IEC 1043 Class I
- Minimal shadow and diffraction effects
- Well-defined acoustical microphone separation
- Specially designed for use with Hand-held Analyzer Type 2270

Brüel & Kjær

Introduction

Fig. 1
Sound Intensity Probe Kit Type 3654, supplied in a robust carrying case with space for Hand-held Sound Intensity System Type 2270-G and optional accessories

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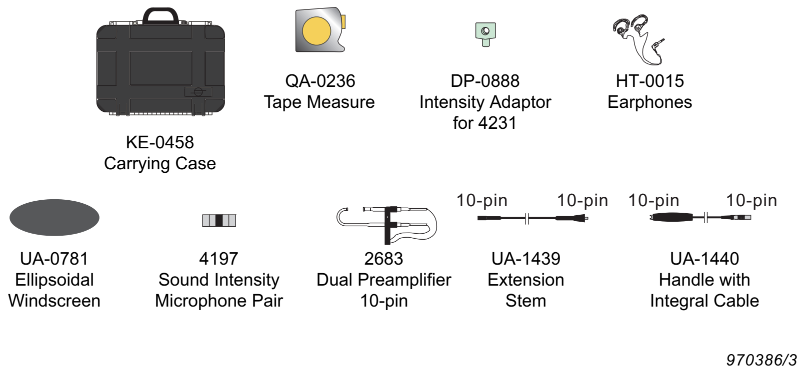
The measurement of sound intensity (sound power per unit area) is increasingly being used as a routine technique in a wide range of noise investigations. The method permits the determination of sound power from direct measurement of sound intensity, even in situations where pressure-based measurements would be impossible. Since the method does not require special acoustic environments such as reverberation and anechoic chambers, significant savings can also be made.

Measuring sound intensity accurately using a two-microphone technique requires a reliable sound intensity probe set that has a matched microphone pair to obtain information on both the instantaneous pressure and pressure gradient in the sound field. The microphones are separated by a fixed distance in the sound field, and the microphone signals are fed to a sound intensity processor that calculates the sound intensity. The sound intensity is calculated from the time average of the sound pressure multiplied by the particle velocity (calculated from the measured pressure gradient). Such a system measures the component of the sound intensity along the probe axis and also indicates the direction of energy flow.

Note: Microphone Pair Type 4197 is a direct replacement for the earlier Microphone Pair Type 4181. The improvements in Type 4197 include stainless steel alloy diaphragm, a robust grid, a calibration chart and improved sensitivity. Otherwise the specifications of Types 4197 and 4181 are virtually the same.

Dual Preamplifier Type 2683 with Microphone Pair Type 4197, Extension Stem UA-1439 and Handle with Integral Cable UA-1440 can also be used with other intensity systems, e.g., NEXUS™ Conditioning Amplifier Type 2691.

Fig. 2
The Sound Intensity Probe Kit Type 3654



Probe Description

The sound intensity probe is constructed with a face-to-face design. It consists of a robust frame that holds the microphone preamplifier(s) and matched microphones in a face-to-face configuration. The distance between the microphones is defined by solid plastic spacers that are held in place by threaded studs on the microphone grids. Sound is constrained to act on each microphone through a narrow slit between the spacer and the microphone grid. This arrangement gives well-defined acoustic separation of the microphones and minimises shadow and reflection effects.

The probe is strong but lightweight and is held using a handle with an extension rod. The probe can be connected to Type 2270 via a cable or an extension rod. The probe kit includes an ellipsoidal windscreen and is supplied in a robust carrying case (Fig.1). The case also has space for the Handheld Sound Intensity System Type 2270-G and optional accessories (Sound Calibrator Type 4231, Sound Intensity Calibrator Type 4297).

Sound Intensity Microphone Pair Type 4197

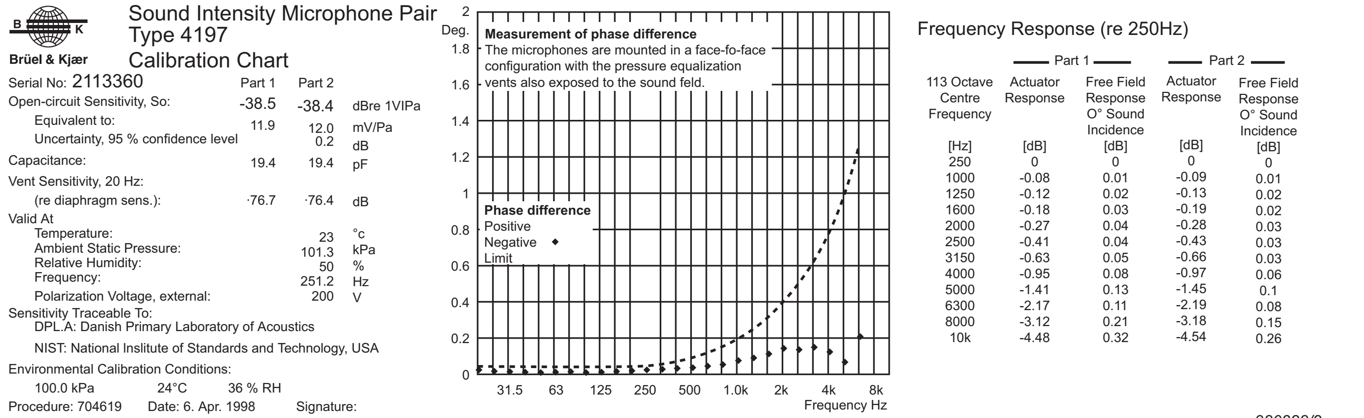
Phase matching of the 1/2″ microphone pair Type 4197 is better than 0.05 degrees between 20 Hz and 250 Hz, and is better than f/5000 degrees at higher frequencies, where f is the frequency. Such phase matching is the result of the integral microphone phase-corrector units (patented) which are fitted to the Type 4197 microphones. The normalised microphone frequency responses differ by less than 0.2 dB up to 1 kHz and by less than 0.4 dB up to 7.1 kHz.

Type 4197 is supplied with 8.5, 12 and 50 mm spacers. Calibration data provided (Fig. 4) include phase matching up to a 1/3-octave centre frequency of 6.3 kHz, microphone sensitivities at 250 Hz, actuator responses and individual free-field frequency responses valid for the microphones mounted on a 1/4″ preamplifier.

The microphones operate on a polarization voltage of 200 V.

Brüel & Kjær also supplies a 1/4″ Microphone Pair Type 4178 which are selected to have phase match to better than 0.2° from 20 Hz to 1 kHz and sensitivity matched to better than 1 dB.

Fig. 3 *Calibration chart supplied with the Type 4197 microphone pair. The measured microphone phase matching and individual microphone free-field responses are given*


Sound Intensity Microphone Pair Type 4197 Calibration Chart

Brüel & Kjær

	Part 1	Part 2	
Serial No: 2113360			
Open-circuit Sensitivity, So:	-38.5	-38.4	dBre 1VlPa
Equivalent to:	11.9	12.0	mV/Pa
Uncertainty, 95 % confidence level		0.2	dB
Capacitance:	19.4	19.4	pF
Vent Sensitivity, 20 Hz: (re diaphragm sens.):	-76.7	-76.4	dB
Valid At			
Temperature:		23	°c
Ambient Static Pressure:		101.3	kPa
Relative Humidity:		50	%
Frequency:		251.2	Hz
Polarization Voltage, external:		200	V

Sensitivity Traceable To:
DPL.A: Danish Primary Laboratory of Acoustics
NIST: National Insitute of Standards and Technology, USA

Environmental Calibration Conditions:
100.0 kPa 24°C 36 % RH

Procedure: 704619 Date: 6. Apr. 1998 Signature:

Frequency Response (re 250Hz)

1/3 Octave Centre Frequency	Part 1 Actuator Response	Part 1 Free Field Response O° Sound Incidence	Part 2 Actuator Response	Part 2 Free Field Response O° Sound Incidence
[Hz]	[dB]	[dB]	[dB]	[dB]
250	0	0	0	0
1000	-0.08	0.01	-0.09	0.01
1250	-0.12	0.02	-0.13	0.02
1600	-0.18	0.03	-0.19	0.02
2000	-0.27	0.04	-0.28	0.03
2500	-0.41	0.04	-0.43	0.03
3150	-0.63	0.05	-0.66	0.03
4000	-0.95	0.08	-0.97	0.06
5000	-1.41	0.13	-1.45	0.1
6300	-2.17	0.11	-2.19	0.08
8000	-3.12	0.21	-3.18	0.15
10k	-4.48	0.32	-4.54	0.26

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Type 4178 is supplied with 6 and 12 mm spacers, along with calibration charts giving the individually measured free-field frequency response for each microphone.

IEC 1043 Standard

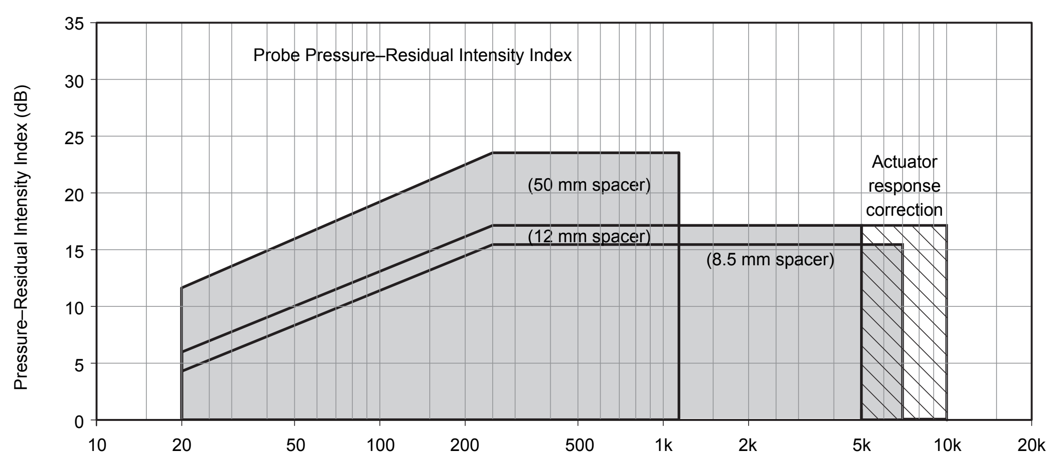
The IEC 1043 standard (Electroacoustics – Instruments for the measurement of intensity – measurement with pairs of pressure sensing microphones, 1993) distinguishes between Probe, Processor and Instrument and classifies them according to the measurement accuracy achieved. There are two degrees of accuracy, Class 1 and Class 2. The Brüel & Kjær probe set complies with IEC 1043 Class 1 which has the most stringent tolerance requirements.

Note: the IEC standard only specifies the frequency range from centre frequencies of 50 Hz to 6.3 kHz in 1/3-octave bands.

Frequency Range

The useful free-field frequency range according to IEC 1043 Class I for Type 3654 using the various microphone and spacer combinations is from 1/3-octave centre frequencies of 50 Hz to 6.3 kHz, however, using the actuator response correction described in an article by Prof. F. Jacobsen in Brüel & Kjær's Technical Review No. 1, 1996 (BV-0048), the frequency response can be extended to 10 kHz using just the 12 mm spacer. The actual frequency range in practice depends on the difference between the pressure and intensity levels, i.e., Pressure-Intensity Index, which is dependent on the nature of the sound field and the phase response deviation between the probe and processor channels.

Fig. 4 *Specified frequency and Pressure-Residual Intensity Index ranges for the probe (Pressure-Residual Intensity Index = Pressure Level – Intensity Level (measured in a closed coupler)). Frequency axis is in 1/3-octave centre frequencies*



The overall frequency ranges are shown in Fig. 4 for 1/2″ Microphone Pair Type 4197 with 8.5, 12 and 50 mm spacers. The frequency range depends on the difference between the pressure level and the intensity level. In most field measurements, the sound intensity level is lower than the sound pressure level. The ability of a sound intensity instrument to measure intensity levels much lower than the pressure level depends on the probe and processor phase matching. The difference between pressure and intensity levels is called the Pressure-Intensity Index which is denoted by δ_{pI} and is normally a positive quantity.

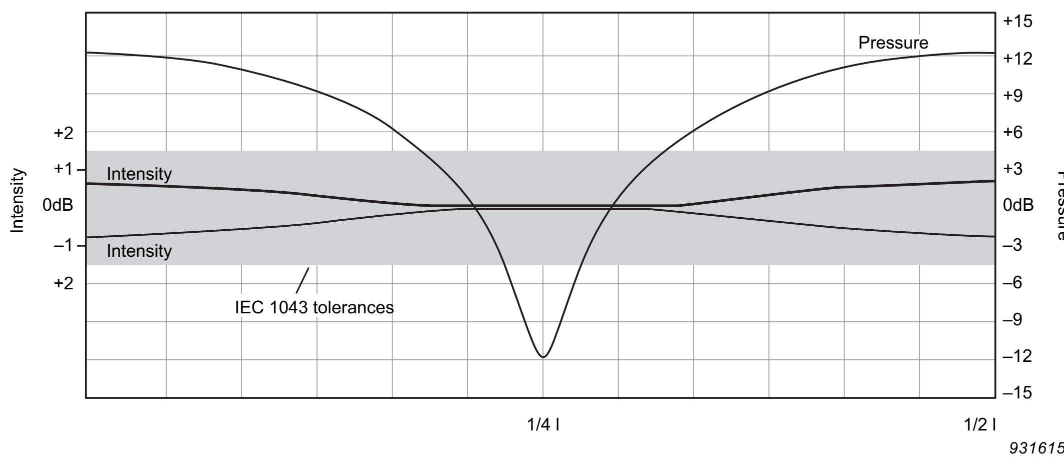
The Pressure-Residual Intensity Index of the measurement instrumentation is δ_{pI0} (shown for the probe by the limits of the shaded area in Fig. 4). The phase (mis)match of the system determines δ_{pI0}, and the effect on the accuracy of a measured sound intensity level is determined by the value chosen for the constant *K*. If *K* is 7 dB, then an accuracy of ± 1 dB can be expected. If *K* is 10 dB then the accuracy will be ±0.5 dB (the sign of this bias error depends on the sign of the system's phase mismatch). Measurements must be restricted to values of δ_{pI} given by:

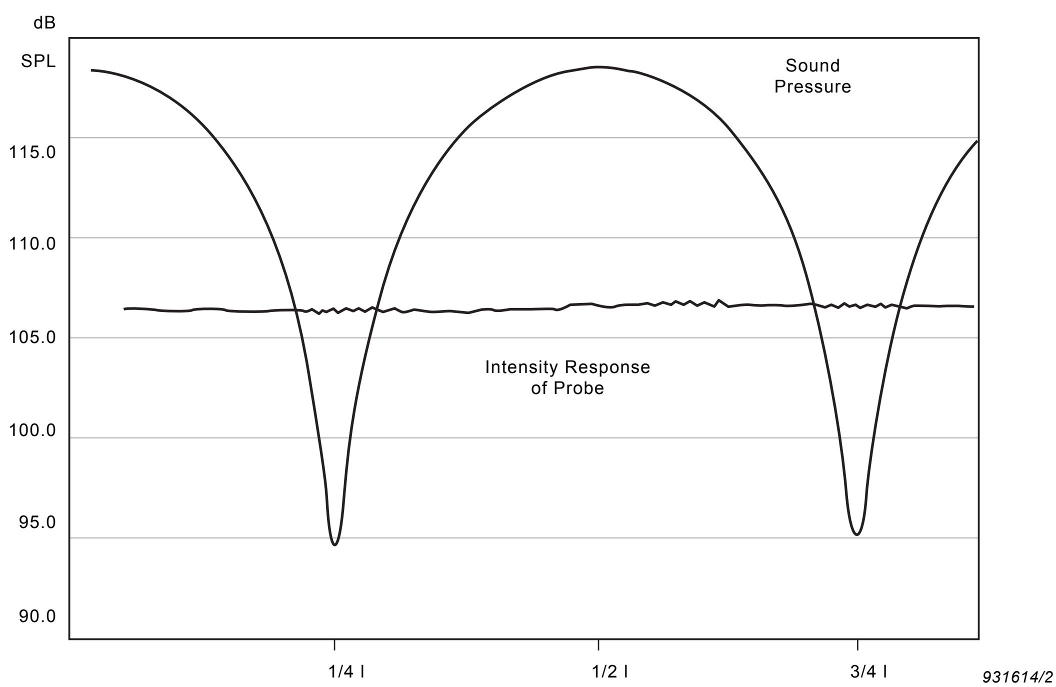
$$\delta_{pI} \leq \delta_{pI_0} - K$$

The Pressure-Residual Intensity Indices for the intensity probe set, shown in Fig. 4 (solid lines), are derived directly from the phase-matching specifications.

As the static pressure equalization vent may cause problems, IEC 1043 specifies that probes designed to operate at frequencies below 400 Hz must be tested in a plane standing wave field. The standing wave ratio must be 24 dB at a frequency between 125 and 400 Hz. Fig. 5 illustrates the performance of the Brüel & Kjær intensity probe for this test at 125 Hz.

Fig. 5
The upper graph illustrates the calculated intensity response limits relative to a standing wave, for a probe consisting of Sound Intensity Microphone Pair Type 4197 and Dual Preamplifier Type 2683. The calculation is valid for the maximum phase deviation specified for the microphone pair and preamplifier configuration and for field conditions according to IEC 1043 (50 mm spacer at 125 Hz and a standing wave ratio of 24 dB). In practice the intensity response of the probe is significantly better as shown in the typical measurement in the lower graph

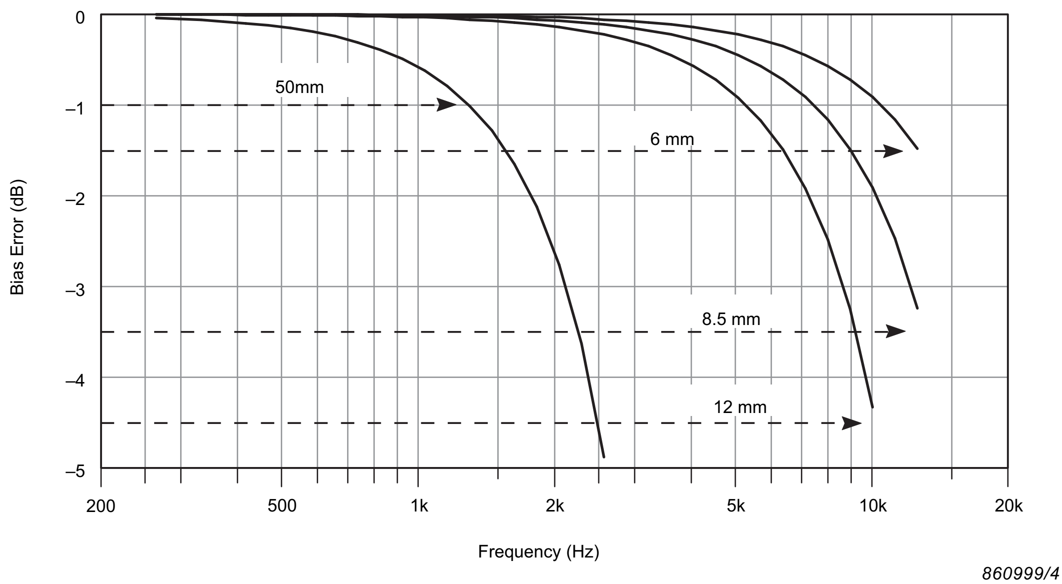




High-Frequency Limit

The upper limit of the frequency range for a sound intensity probe set depends on the length of the microphone spacer. Approximating the pressure gradient using two microphones separated by a short distance in the sound field leads to an underestimate of the sound intensity level, but the error is less than 1 dB as long as the distance between the microphones is less than one sixth of the wavelength. This means that for high-frequency measurements, a short spacer should be used. The bias error is plotted as a function of frequency for the different microphone spacers in Fig. 6. To keep this error to less than 1 dB, the appropriate spacer is chosen for the frequency range of interest. 50, 12 and 8.5 mm spacers are used with 1/2″ microphones up to 1/3-octave centre frequencies of 1.25, 5 and 6.3 kHz respectively; 12 mm and 6 mm spacers with 1/4″ microphones up to 1/3-octave centre frequencies of 5 and 10 kHz respectively.

Fig. 6
High-frequency bias error in sound intensity measurements (for plane waves, 0° incidence). The upper frequency limits (– 1 dB error) for the different spacers are indicated

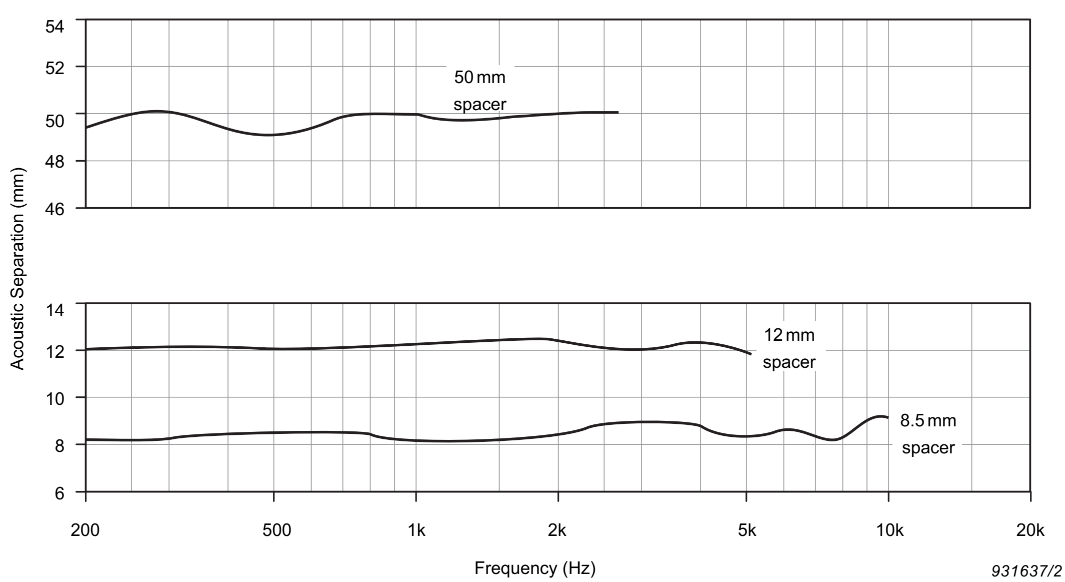


Extension of frequency range to 10 kHz using 1/2″ microphones and 12 mm spacer is described in Brüel & Kjær Technical Review No.1, 1996 and Product Data sheet for Type 2270 (BP-2199).

Effective Acoustical Separation of Probe Microphones

It is important that a sound intensity probe does not disturb the sound field it is measuring. The face-to-face configuration and the optimised mechanical design of the Brüel & Kjær probe means that the disturbance of the sound field is very small.

Fig. 7
Measurement of the variation of effective acoustical separation as a function of frequency for Type 4197 microphones with 50 mm, 12 mm and 8.5 mm spacers



The spacers used to separate the microphone pairs in the sound field are designed to give acoustic separations of 6, 8.5, 12 and 50 mm. Their physical lengths differ slightly from these values. The effective acoustical separation of the microphones varies slightly as a function of frequency due to reflections. This effect is minimised by the solid spacers that separate the microphones, and the distance variation is less than 0.5 mm for the 12 mm spacer as shown in Fig. 7. The effect on the accuracy of the measured sound intensity is consequently very small.

Fig. 8
Comparison measurement of sound intensity measured using Microphone Pair Type 4197 with the actual sound intensity

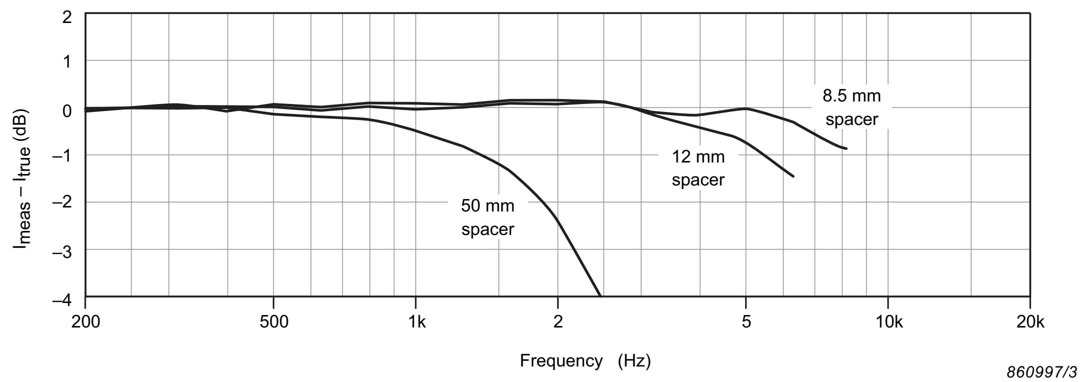
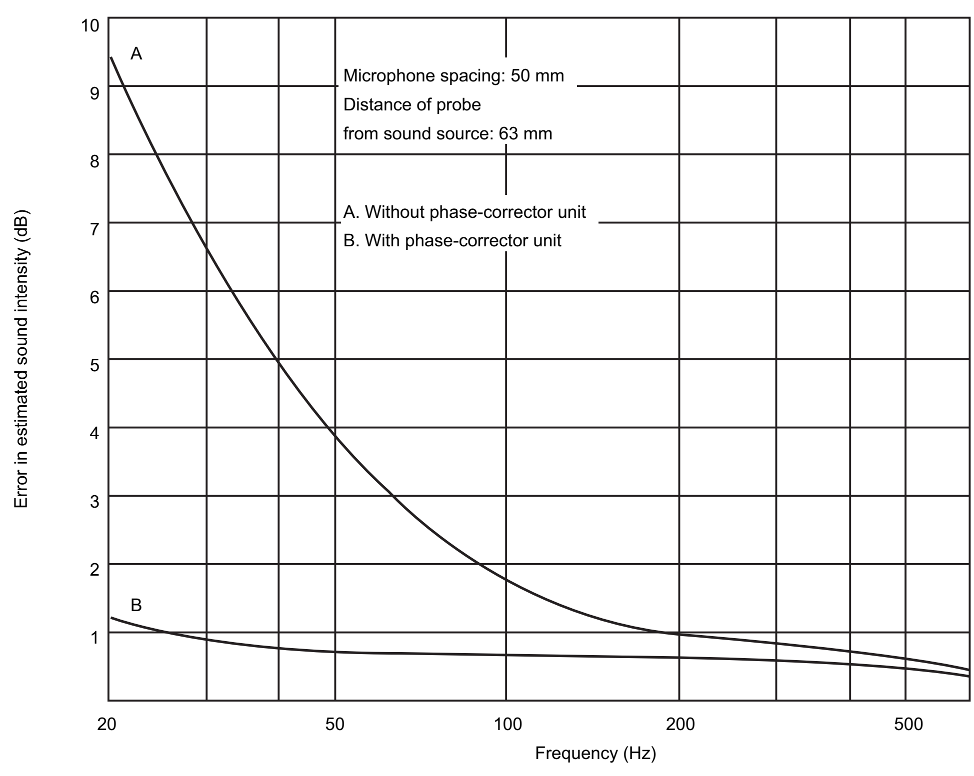


Fig. 8 shows the difference between the true intensity and the measured intensity in a free-field. The typical response shown in this graph includes all the possible sources of error: phase mismatch, free-field corrections, microphone distance variation and the high-frequency approximation error (the latter giving a –1 dB error at centre frequencies of 1.25, 5 and 6.3 kHz, respectively).

Patented Microphone Phase-Corrector Units

The phase matching specified for the Type 4197 microphone pair is retained even in sound fields with very high pressure-level gradients, such as those found close to point sources. This is a benefit of the patented phase-corrector units which are fitted to these microphones. Ordinary condenser microphones can have their phase responses altered if there is a difference between the pressure level at the pressure equalisation vent and that at the diaphragm. Type 4197 microphones are, however, essentially insensitive to sound at the vent and the accuracy of near-field measurements at low frequencies is consequently increased (Fig. 9).

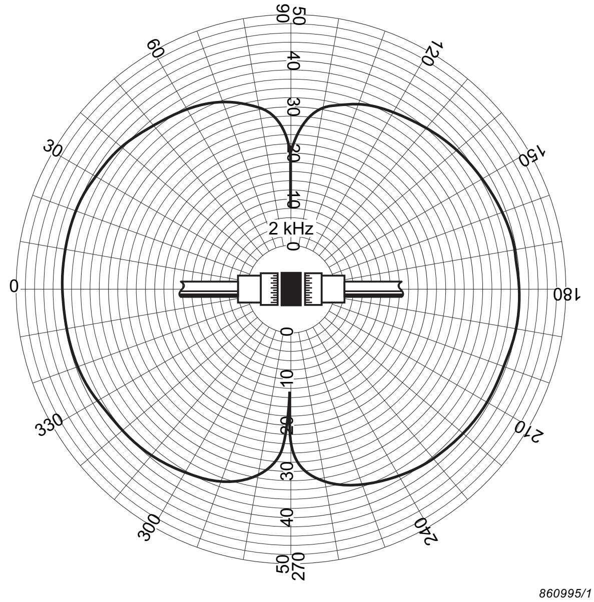
Fig. 9
The phase-corrector units fitted to the Type 4197 suppress vent sensitivity and result in more accurate near-field measurements



Directional Characteristics

Typical directional characteristics for a sound intensity probe are given in Fig. 10, which shows the measured intensity as a function of angle of incidence. This figure-of-eight characteristic is due to the fact that a sound intensity system measures the component of the sound intensity along the probe axis, i.e., $I_{meas} = I\cos\theta$. The minimum feature of the probe's characteristics can be used to help locate sound sources.

Fig. 10
Measured directional intensity characteristics for a probe set fitted with Type 4197 microphones and a 12 mm spacer at 2 kHz



Calibration

Phase calibration of the 1/2″ Microphone Pair Type 4197 is done at Brüel & Kjær by subjecting the two microphones to the same sound signal in a pressure coupler and is available on the calibration chart. This individual phase calibration can be used to derive the actual Pressure-Residual Intensity Index for the microphone pair. If only amplitude (pressure) calibration is required, the two channels can be calibrated separately using a Pistonphone Type 4228 or together using Sound Calibrator Type 4231 with Coupler DP-0888.

Fig. 11
Sound Intensity Calibrator Type 4297 with a Sound Intensity Probe in place for calibration. The advantage of this calibrator is that the probe need not be dismantled to perform a calibration. Further details can be found in the separate Product Data for Type 4297

Compliance with Standards

CE, C-Tick	CE-mark indicates compliance with: EMC Directive and Low Voltage Directive. C-Tick mark indicates compliance with the EMC requirements of Australia and New Zealand.
Safety	EN/IEC 61010–1: Safety requirements for electrical equipment for measurement, control and laboratory use. ANSI/UL 61010–1: Safety requirements for electrical equipment for measurement, control and laboratory use.
EMC Emission	EN/IEC 61000–6–3: Generic emission standard for residential, commercial and light industrial environments. EN/IEC 61000–6–4: Generic emission standard for industrial environments. CISPR 22: Radio disturbance characteristics of information technology equipment. Class B Limits. FCC Rules, Part 15: Complies with the limits for a Class B digital device. This ISM device complies with Canadian ICES–001 (interference causing equipment standard)
EMC Immunity	EN/IEC61000–6–1: Generic standards – Immunity for residential, commercial and light industrial environments. EN/IEC 61000–6–2: Generic standards – Immunity for industrial environments. EN/IEC 61326: Electrical equipment for measurement, control and laboratory use – EMC requirements. **Note:** The above is only guaranteed using accessories listed in this Product Data sheet.

Specifications – Sound Intensity Probe Kit Type 3654

Matched Sound Intensity Microphone Pairs:

Sound intensity free-field frequency ranges (centre frequency – 1/3-octave) with 1/2″ microphones Type 4197 connected to Dual Preamplifier Type 2683 (IEC 1043 Class 1):
8.5 mm spacer: 250 Hz to 6.3 kHz (δ_{pI0} > 15.3 dB)*
12 mm spacer: 250 Hz to 5.0 kHz (δ_{pI0} > 16.8 dB)
50 mm spacer: 20 Hz to 1.25 kHz (δ_{pI0} > 23 dB above 250 Hz)

* Pressure-Residual Intensity Index

Sound intensity free-field frequency ranges with 1/4″ microphones Type 4178 (optional accessory):
6 mm spacer: max. 10.0 kHz
12 mm spacer: max. 5.0 kHz

DIMENSIONS:
Length of Extension Stem: 42 cm (16.5 in)
Width: 43 mm (1.7 in)

WEIGHT:
Incl. handle: 0.35 kg (0.77 lb)
In case: 6.50 kg (14.3 lb)

Specifications – Sound Intensity Microphone Pair Type 4178

Sensitivity: 4 mV/Pa
Frequency: 4 Hz–100 kHz
Dynamic Range: 28–164 dB
Temperature: –40 to +150 °C (–40 to +302 °F)
Polarization: 200 V External

MICROPHONE MATCHING SPECIFICATIONS TYPE 4178
Phase Response Difference (1/3-octave centre frequencies):
100 Hz–200 Hz: ±20 deg/f [Hz]
200 Hz–1 kHz: ±0.1 deg
1 kHz–20 kHz: ±0.1 deg × f [kHz]
Amplitude Response Difference (normalised at 200 Hz):
<0.3 dB: 100 Hz to 10 kHz
<0.5 dB: 100 Hz to 20 kHz

Specifications – Sound Intensity Microphone Pair Type 4197

Diameter		1/2″
Polarization voltage	V	200
Open-circuit sensitivity	mv/Pa	11.2[†]
	dB re 1 V/Pa	−39
Free-field frequency response 0° incidence	±1 dB	5 Hz to 12.5 kHz[*]
	±2 dB	0.3 Hz to 20 kHz
Resonance frequency		34 kHz
Lower limiting frequency	−3 dB	0.14 Hz
Vent sensitivity re diaphragm sensitivity	at 20 Hz	<−64 dB[†] (−18 dB/octave)
Polarized cartridge capacitance	at 250 Hz	19.5 pF[†]
Cartridge thermal noise		20.0 dB(A)
Upper limit of dynamic range	Distribution <3%, 100 Hz	162 dB SPL
Temperature coefficient	−10°C to +50°C, 250 Hz	−0.002 dB/°C
Ambient pressure coefficient	at 250 Hz	−0.0007 dB/hPa
Humidity coefficient	100% RH	<0.1 dB
Vibration sensitivity	at 1 m/s^2	65.5 dB SPL
Magnetic field sensitivity	50 Hz, 80 A/m	6 to 34 dB SPL
Thread for preamplifier mounting		5.7 — 60 UNS
Microphone Matching Specifications		
Phase response difference (absolute value) (1/3-octave centre frequencies)		<0.05°: 20 Hz to 250 Hz[†] $<\frac{f[\mathrm{Hz}]^\circ}{5000}$: 250 Hz to 6.3 kHz[†]
Amplitude response difference	Normalized at 200 Hz	<0.2 dB: 20 Hz to 1 kHz <0.4 dB: 20 Hz to 7.1 kHz
Sensitivity difference	at 250 Hz	<1 dB
Polarized capacity difference		<1.0 pF

[*] Individually Calibrated

Specifications – Dual Preamplifier Type 2683

Phase matching		<0.015° at 50 Hz (20 pF mic. capacitance) f[kHz] × 0.06°: 250 Hz to 10 kHz
Electrical noise re microphone sensitivity[*]	1/4″ 6.4 pF dummy	39.2 dB SPL (A)
	1/2″ 19.5 pF dummy	19.4 dB SPL (A)
Input impedance	Channel A	typically >15 GΩ‖1.1 pF
	Channel B	typically >15 GΩ‖0.4 pF
Attenuation	For 1/2″ microphones	Ch. A = 0.6 dB; Ch. B = 0.3 dB
	For 1/4″ microphones	Ch. A = 1.7 dB; Ch. B = 0.7 dB
Other specifications		Refer to Product Data (BP 1584) for Type 2670

[*] This corresponds to a total (Microphone + Preamplifier) noise floor of 39.3 dB SPL (A) and 22.7 dB SPL (A), respectively.

Note: All values are typical at 25°C (77°F) unless measurement uncertainty is specified. All uncertainty values are specified at 2 σ (i.e., expanded uncertainty using a coverage factor of 2)

Ordering Information

Type 3654 includes the following accessories:

- Type 4197: 1/2″ Microphone Pair including spacers:
  - UC-5349: 8.5 mm spacer
  - UC-5269: 12 mm spacer
  - UC-5270: 50 mm spacer
- Type 2683: Dual Preamplifier
- UA-1439: Extension Stem
- UA-1440: Handle with Integral Cable
- UA-0781: Ellipsoidal Windscreen
- DP-0888: Coupler
- HT-0015: Earphones
- AO-0522: Adaptor Lemo to Jackplug
- QA-0236: Tape Measure
- KE-0379: Carrying Case

OPTIONAL ACCESSORIES

CALIBRATION EQUIPMENT

Type 4228	Pistonphone
Type 4231	Sound Calibrator
Type 3541-A	Sound Intensity Calibrator (includes Type 4228)
Type 4297	Sound Intensity Calibrator

MICROPHONES

Type 4178	1/4″ Sound Intensity Microphone Pair (with 6 and 12 mm spacers)

SPACERS:

For 1/4″ Microphones Type 4178

UC-0196	6 mm spacer
UC-0195	12 mm spacer

EXTENSION CABLES

AO-0441	3 m Single Cable Extension (10-pin LEMO)
AO-0442	10 m Single Cable Extension (10-pin LEMO)
JP-1040	Branched plug 10-pin LEMO to two 7-pin LEMO

BP 2324 – 11 2010-10

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